Attachment 2

Defense Information Systems Agency

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Consulting Report

Electromagnetic Compatibility Analysis of the Alfred Mann Foundation Medical Micropower Network

JSC-CR-10-058

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Prepared for:

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14. ABSTRACT The Alfred Mann Foundation (AMF) has requested that the Federal Communications Commission consider changing the United States (US) Table of frequency allocations to accommodate a medical service allocation in the 413 – 457 MHz band. The 410 – 450 MHz band is currently allocated on a primary basis to the Federal Government for fixed, mobile, space research and radiolocation services. To support the spectrum reallocation request, the AMF requested the Department of Defense Joint Spectrum Center to perform an electromagnetic compatibility analysis of the proposed Medical Micropower Network and US Government communications-electronics systems authorized to operate in the 410 – 450 MHz frequency band.		
15. SUBJECT TERMS Alfred Mann Foundation, AMF, Medical Micropower Network, MMN, Master Control Unit, MCU, Interacting System Device, ISD, Electromagnetic Interference, EMI, Electromagnetic Compatibility, EMC, Government Master File, GMF, Frequency Record Resource System, FRRS, Radio Frequency Interference ,RFI		

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EXECUTIVE SUMMARY

The Alfred Mann Foundation (AMF) is developing a Medical Micropower Network (MMN) and envisions the MMN being used to aid patients recovering from neurological muscular damage due to injury or disease. The MMN consists of microstimulators, referred to as Interacting System Devices (ISD) that are implanted in a human body, and an external control apparatus, referred to as the Master Control Unit (MCU).

The AMF design of the MMN plans for the MCU to be within several meters of the patient and to communicate with the implanted ISDs using a Radio Frequency (RF) link. AMF designed the MMN to be frequency agile and is proposing to operate on one of four, 6 MHz bandwidth, channels in the 413 – 457 MHz frequency band. The MMN was designed to simultaneously monitor the noise level in each of the four channels and to dynamically switch to a channel with an acceptable noise level.

To support this design, AMF has requested the Federal Communications Commission to consider adding a medical service allocation in the 413 – 457 MHz frequency band. The 410 – 420 MHz frequency band is allocated on a primary basis to the Federal Government for fixed, mobile, and space research services. The 420 – 450 MHz frequency band is allocated on a primary basis to the Federal Government for radiolocation services and to the amateur radio service on a secondary basis. The 450 – 460 MHz frequency band is allocated to the private sector for land mobile, fixed, remote pickup and maritime services on a primary basis. Since the MMN is proposing to operate on a non-interference/non-protected basis with incumbent services in the 413 – 457 MHz frequency range; AMF designed the MMN with multiple techniques to mitigate interference into and from incumbent systems.

AMF requested the Joint Spectrum Center evaluate the Electromagnetic Compatibility (EMC) of the proposed MMN with incumbent Federal Government Communications-Electronics (C-E) systems operating in the 410 – 450 MHz frequency band. The EMC between the MMN and commercial systems operating above 450 MHz and amateur radio systems operating below 450 MHz was not considered in this analysis.

The proposed MMN is a portable wireless medical application with unknown future geographic distribution; therefore, an appropriate EMC analysis was performed that was not dependent on the fixed locations of incumbent Federal Government C-E Systems. The EMC analysis was performed by establishing interference criteria, in terms of Interference-to-Noise ratio (I/N) threshold, for both the MMN and Government C-E systems. Using the established I/N threshold, the propagation path loss required to reduce an on-tune signal level, where the interfering signal is assumed to operate within the occupied bandwidth of the victim receiver, from a potential interfering transmitter below the interference criteria of a receiver was calculated. The required propagation loss was then entered into an inverse RF propagation model to calculate the predicted Required Separation Distance (RSD). The RSD is defined as the separation between the MMN and a Federal Government C-E system to preclude the potential for Radio Frequency Interference (RFI).

EMC Analysis of the MMN into Federal Government C-E Systems

When the MMN operates in the 410 – 420 MHz frequency band, the RSDs calculated from the MMN transmitters into Government C-E systems were less than 0.31 km. When the MMN operates in the 420 – 450 MHz frequency band, the RSDs calculated into fixed radiolocation systems were less than 0.41 km when the MMN is operating outdoors and less than 0.32 km when operating indoors. These predicted RSDs result from the MMN transmitters' low equivalent isotropic radiated power, duty cycle, and low antenna heights. These factors combined with the dynamic channel switching capability of the MMN transmitters and anticipated low volume of MMN systems indicates that the MMN system should be operationally compatible and not cause unacceptable interference into Government C-E systems currently authorized to operate in the 410 – 450 MHz band.

EMC Analysis of the Federal Government C-E Systems into the MMN

When the MMN operates indoors in the 410 – 420 MHz frequency band, the RSDs calculated from fixed Federal Government land mobile base station transmitters into the MMN system were less than 1.14 km into the MCU and 0.34 km into an implanted ISD. The MMN interference mitigation techniques of on-tune signal notching and dynamic channel switching may effectively eliminate the potential for RFI and allow the MMN to operate simultaneously with C-E systems in the 410 – 420 MHz frequency band at distances less than the calculated RSD.

When the MMN operates indoors in the 420 – 450 MHz frequency band, the RSDs calculated from Federal Government fixed radiolocation transmitters were less than 18.71 km into the MCU and 5.38 km into an implanted ISD. The MMN's time division multiple access architecture and coding schemes increase the probability of the MMN operating without interference at distances less than the predicted RSDs. This is due to the anticipated low probability that the interfering and desired signals are received simultaneously, forward error correction techniques and the frequency agility of the MMN that is designed to dynamically switch channels when RFI is detected.

Recommendations

Testing is recommended to determine the effectiveness of the MMN interference mitigation methods to enable the MMN to successfully operate in a high powered Federal Government system environment, specifically in the presence of on-tune narrow bandwidth Federal Government land mobile systems operating in the 410 – 420 MHz frequency band and radiolocation systems operating in the 420 – 450 MHz frequency band.

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1. INTRODUCTION

1.1 BACKGROUND

The Alfred Mann Foundation (AMF) is developing a Medical Micropower Network (MMN) and envisions the MMN being used to aid patients recovering from neurological muscular damage due to injury or disease. The MMN consists of microstimulators, referred to as Interacting System Device (ISD) that are implanted in a human body, and an external control apparatus, referred to as the Master Control Unit (MCU)[1].

The MCU will typically operate within several meters of the patient and will communicate with the implanted ISDs using a Radio Frequency (RF) link. AMF designed the MMN to be frequency agile and proposed to operate on one of four, 6 MHz bandwidth, channels in the 413 – 457 MHz frequency range [1].

To support this design, AMF has requested the Federal Communications Commission (FCC) to consider adding a medical service allocation in the 413 – 457 MHz frequency band. The 410 – 420 MHz frequency band is allocated on a primary basis to the Federal Government for fixed, mobile, and space research services. The 420 – 450 MHz frequency band is allocated on a primary basis to the Federal Government for radiolocation services and to the amateur radio service on a secondary basis. Since the MMN is proposing to operate on a non-interference/non-protected basis with incumbent operations in the 413 – 457 MHz frequency band; AMF designed the MMN with multiple techniques to mitigate interference into and from incumbent services.

AMF requested the Joint Spectrum Center to evaluate the Electromagnetic Compatibility (EMC) of the proposed MMN with incumbent Federal Government Communications-Electronics (C-E) systems operating in the 410 – 450 MHz frequency band.

1.2 OBJECTIVE

The objective was to analyze the EMC of the proposed MMN with Federal Government C-E systems operating in the 410 – 450 MHz band. The EMC of the proposed MMN with commercial systems operating above 450 MHz and amateur radio systems operating below 450 MHz was not considered in this analysis.

1.3 APPROACH

The proposed MMN system is a portable wireless medical application with unknown future geographic distribution; therefore, an appropriate EMC analysis was performed that was not dependent on the fixed locations of incumbent Federal Government C-E Systems. The EMC analysis was performed by establishing interference criteria, in terms of Interference-to-Noise ratio (I/N) threshold, for both the MMN and Government C-E systems. Using the established I/N threshold, the propagation path loss required to reduce an on-tune signal level, where the interfering signal is assumed to operate within the occupied bandwidth of the victim receiver, from a potential interfering transmitter below the interference criteria of a receiver was calculated. The required propagation path loss was then entered into an inverse RF propagation model to calculate the predicted Required Separation Distance

(RSD). The RSD is defined as the separation between the MMN and a Federal Government C-E system to preclude the potential for Radio Frequency Interference (RFI).

To initiate the EMC analysis, the Government Master File (GMF) and Frequency Resource Record System (FRRS) frequency assignment databases were queried to identify Federal Government C-E systems authorized to operate in the 413 – 450 MHz frequency band. For each equipment nomenclature contained in the GMF and FRRS database query, the technical parameters including transmit power, emission bandwidth, modulation type, duty cycle, and antenna type and gain, were obtained from either the assignment data or the Defense Department Form 1494, Application for Equipment Frequency Allocation. For these C-E systems, the equipment was categorized by communication service and station class, and applicable interference threshold criteria were established. For each communication service type, and station class, the antenna height data was analyzed to determine a representative antenna height for RF propagation path loss calculations.

AMF provided the design specification [1] in an email dated March 15, 2010. Using the data found in this design specification and multiple consultations with AMF technical staff, the AMF receiver interference criteria was calculated and the technical parameters used in the analysis were identified.

On April 12, 2010, a meeting with AMF technical staff members was held to discuss the overall EMC analysis approach utilizing on-tune RSD calculations between the MMN and Government C-E systems. During the meeting, the types of Government C-E systems, number of frequency assignments and equipment nomenclatures identified in the GMF and FRRS database query, interference protection criteria of the Government receivers, and antenna heights proposed to be used in calculating RF propagation losses were presented and discussed. In addition, the technical parameters of the MMN system, interference protection criteria of the MMN receivers, propagation loss values of human tissue, and propagation models to characterize losses between the MMN and Government C-E systems were discussed.

Following this meeting and subsequent discussions with AMF technical staff, general agreement was obtained regarding the EMC analysis approach and technical parameters used in the analysis including the Equivalent Isotropic Radiated Power (EIRP), duty cycle of the MMN transmitters, receiver noise figures, interference criteria of the MMN receivers, propagation loss values of human tissue, and computer models to predict propagation losses in a variety of environmental conditions.

Following these meetings with the AMF technical staff, the RSD values were calculated between incumbent Government C-E systems and the MMN when operating outdoors and inside buildings.

2. SYSTEM DESCRIPTION AND TECHNICAL PARAMETERS

2.1 GOVERNMENT SYSTEMS

Federal Government transmitters and receivers considered in the EMC analysis were identified by querying the GMF and FRRS for all systems with frequency assignments in the 410 – 450 MHz frequency band. The GMF and FRRS data query contained 19,809 transmitter and 19,972 receiver frequency assignments. These assignments comprised 217 unique transmitters and 145 unique receivers designated to operate in the fixed, mobile, radiolocation, and space research services as well as experimental assignments with the station class designation "No Specific Service." The number of transmitters and receivers by station class are listed in Table 2-1.

Table 2-1. Federal Government Transmitters and Receivers by Station Class

Station Class	Number of Transmitters	Number of Receivers
Land Mobile	83	54
Mobile	15	5
Aeronautical Mobile	22	16
Maritime Mobile	6	3
Fixed	57	43
Radiolocation	18	16
Space Research (Space-to-Space)	8	0
No Specific Service (Experimental)	8	8

The locations of current fixed frequency assignments in the continental United States (US) are plotted in Figure 2-1. Locations plotted in blue represent frequency assignments on military bases. The plot reveals that a significant number of the frequency assignments in the 410 – 450 MHz frequency band are located on military bases.

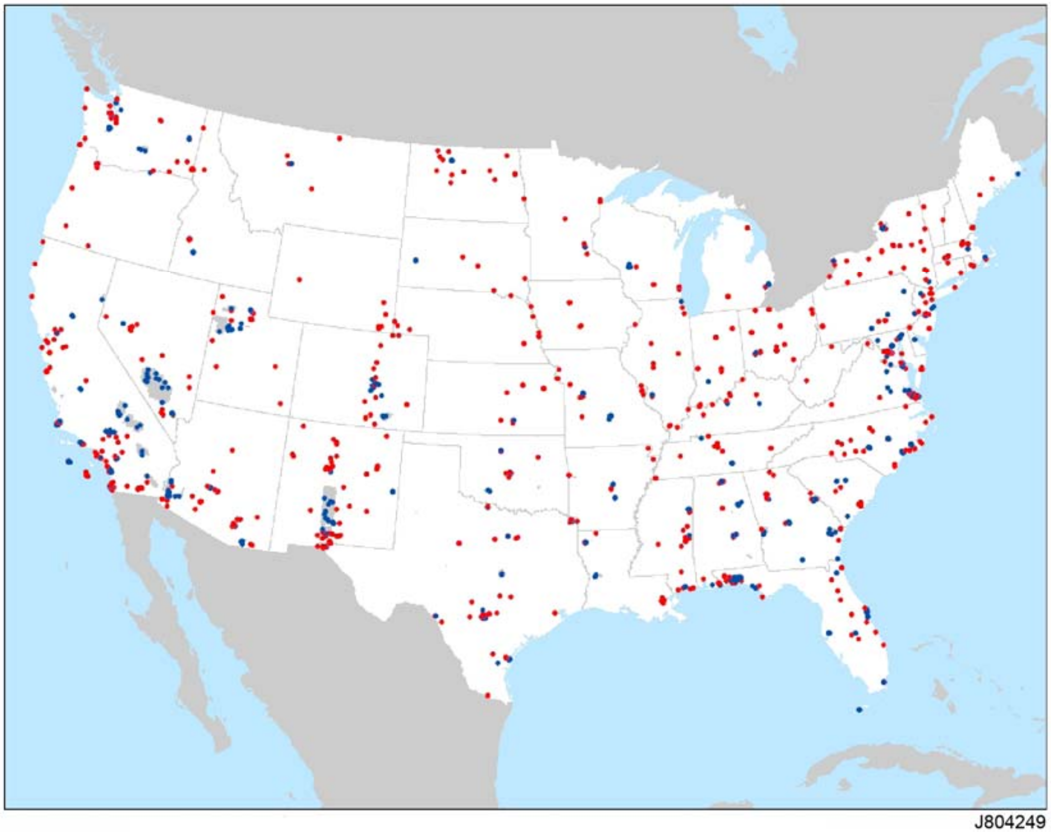

Figure 2-1. Transmitter/Receiver Government Systems in 410 – 450 MHz

The antenna heights reported in the frequency assignment data query were analyzed to determine a representative height by station class. These representative antenna heights were used in RF propagation loss calculations and are listed in Table 2-2.

Table 2-2. Representative Environment Antenna Heights

Station Class		Transmit Antenna Height (m)	Receive Antenna Height (m)
Land Mobile	Base	19	19
	Mobile	2	2
Mobile	Base	19	19
	Mobile	2	2
Aeronautical Mobile	Base	32	32
	Air	5000	5000
Maritime Mobile	Base	9	9
	Mobile	2	2
Radiolocation	Ground Station	34	34
	Mobile Air	5000	5000
	Mobile Ground	2	2
No Specific Service (Experimental)	Base	13	13
	Mobile	2	2
Fixed		21	21

2.2 AMF MMN SYSTEM

2.2.1 MMN System Overview

The design specification [1] states that the MMN is a very low-power Ultra High Frequency (UHF) digital radio network intended primarily for controlling, coordinating, and/or monitoring one or more human or animal implanted devices that enhance treatment of a variety of neuromuscular conditions. The MMN is designed to operate in a "star" topology with a single MCU and one or more ISDs, which must be implanted in the patient's body. The MCU and ISD are shown in Figures 2-2 and 2-3 [2].

Figure 2-2. Medical Micropower Network - Master Control Unit

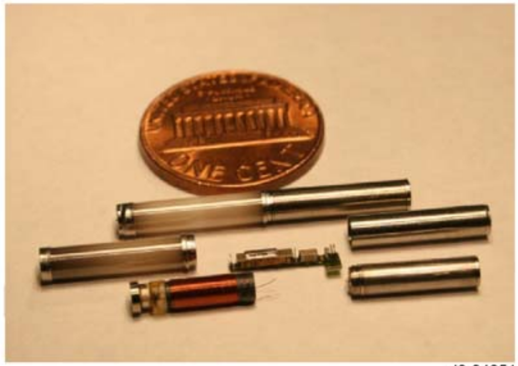

Figure 2-3. Medical Micropower Network – Interacting System Device

The MCU coordinates the electrical stimulation by the ISDs using an RF link operating in the UHF band. Each ISD communicates directly with the MCU, which is responsible for managing all communication within the system. The UHF data link is a Time Division Multiple Access (TDMA) synchronous system and the MMN employs Quadrature Phase-Shift Keying (QPSK) modulation [3]. Since the RF link is proposed to be shared with other communication services operating on a non-interference basis, AMF designed the system to be frequency agile and to operate on one of the four, 6 MHz bandwidth UHF channels listed in Table 2-3.

Table 2-3. MMN Radio Channel Frequencies

MMN Channel Number (Frequency Range) (MHz)	Low Frequency Edge (MHz)	Center Frequency (MHz)	High Frequency Edge (MHz)
1 (413 – 419)	413.919	416.405	418.891
2 (426 – 432)	426.349	428.835	431.321
3 (438 – 444)	438.779	441.265	443.751
4 (451 – 457)	451.209	453.695	456.181
Guard Band 7.458 MHz		Bandwidth 4.972 MHz	

MMN Channel 1 occupies spectrum within the 410 – 420 MHz frequency band allocated for Federal Government fixed, mobile and space research services. MMN channels 2 and 3 occupy spectrum within the 420 – 450 MHz frequency band allocated for Federal Government radiolocation services. MMN Channel 4 occupies spectrum allocated for Non-Federal services [4]. The proposed MMN channels overlaid on the current spectrum allocations are shown in Figure 2-4.

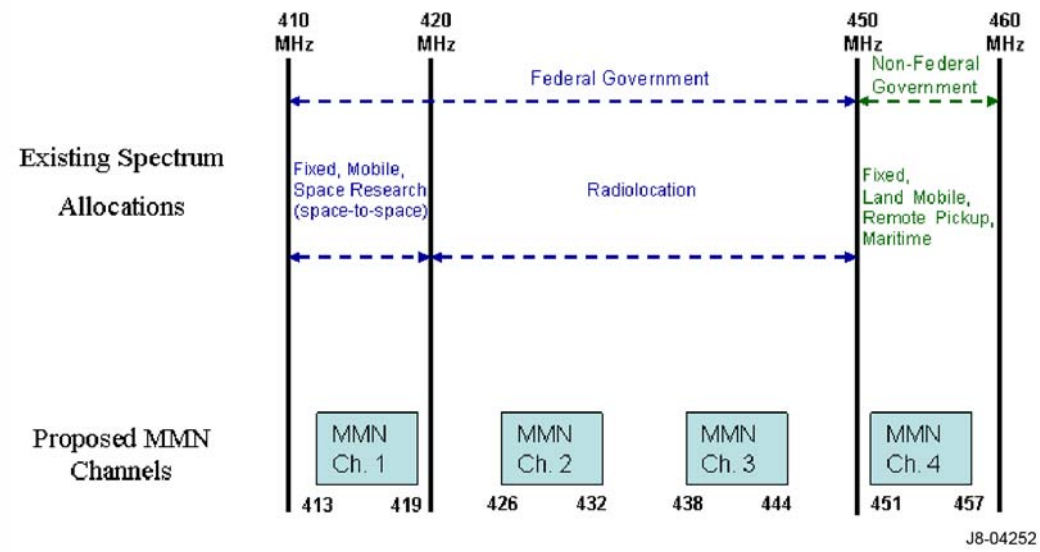

Figure 2-4. 410 – 460 MHz Spectrum Allocation and Proposed MMN Channels

The technical parameters of the MCU and ISD used in the EMC analysis are listed in Table 2-4 [1].

Table 2-4. MMN Technical Parameters

Technical Parameter	MCU	ISD
EIRP (dBm)	0	-20*
Duty Cycle (%)	3	0.05
Emission Bandwidth (MHz)	4.972	4.972
Antenna Gain (dBi)	0	-2.5
Receiver Threshold for 1 x 10^{-3} BER (dBm)	-88	-90
Noise Figure (dB)	11	8
Modulation	QPSK	QPSK
System Loss (dB)	1	1
Typical Antenna Height (m)	1.2	1.2
Body Loss (dB)	Not Applicable	20
*ISD EIRP is typically below -20 dBm when measured immediately outside the body BER – Bit Error Rate		

2.2.2 MMN Interference Mitigation Techniques

The MMN is proposing to operate on a non-interference basis in the 413 – 457 MHz frequency band; therefore, AMF designed the system with multiple techniques to mitigate interference into and from on-tune incumbent systems. These interference mitigation techniques are described in the AMF design specifications [1, 3] and are listed in Table 2-5. A summary of the MMN interference mitigation techniques as applied to the results of the RSD calculations performed in this EMC analysis are described in Sections 5 and 6.

Table 2-5. MMN Interference Mitigation Techniques

Interference Mitigation Technique	Description
Frequency Agility	Operates on one of four, 6 MHz bandwidth channels in the 413 – 457 MHz frequency range
Dynamic Channel Switching	Monitors the noise level in each of the four channels and can dynamically switch to a channel with an acceptable noise level
Frequency Domain Excision	Digitizes RF signals and uses a peak power search algorithm to identify and remove narrow bandwidth interfering signals
TDMA Architecture (Timing/Duty Cycle)	The MMN system transmits with a low duty cycle. If an interfering signal with a similarly low duty cycle is present, there is a very low probability of simultaneous transmissions.
Coding and Forward Error Correction	Coding schemes utilizing Forward Error Correction techniques are the basic mechanism used to protect the system from passing erroneous messages over the communication link. Errors from many sources, including RFI, can be detected and in many cases corrected.
ISD Error Response and Default Activity	An ISD only produces electric stimulations when specifically requested using advanced coding techniques. If the ISD is unable to decode an MCU command, a negative acknowledgement code is received at the MCU and the MCU retransmits the command. When the ISD is unable to decode 7 consecutive MCU transmissions, the ISD assumes communication is lost and attempts to resynchronize to the frame. When the ISD loses communication, the application must ensure that it does not do something harmful to the patient and enters a default activity where electric stimulations are not produced.
Environmental and Utilization Factors	The MMN channels span Federal and Non Federal spectrum allocations varying in service type and utilization distribution which decreases the probability that RFI would be simultaneously present in all four channels.

3. ANALYSIS METHODOLOGY

The EMC analysis was performed by establishing interference criteria, in terms of I/N threshold, for both the MMN and Government C-E systems. Using the established I/N threshold, the propagation path loss required to reduce an on-tune signal level, where the interfering signal is assumed to operate within the occupied bandwidth of the victim receiver, from a potential interfering transmitter below the interference criteria of a receiver was calculated. The required propagation path loss was then entered into an inverse RF propagation model to calculate the predicted RSD. The RSD is defined as the separation between the MMN and a Federal Government C-E system to preclude the potential for RFI.

3.1 INTERFERENCE CRITERIA

The interference criteria for both the Government C-E systems and the AMF MMN receivers were established as described below.

3.1.1 Interference Thresholds for Government Receivers

The interference criteria for the Government C-E system receivers was based on I/N threshold levels by station class and modulation type as listed in Table 3-1 [5].

Table 3-1. I/N Threshold Levels for Government C-E Equipment in the 413 – 450 MHz Band

Station Class	I/N Threshold (dB)	Description
Land Mobile	-6	Digital - 1 dB increase in the receiver noise level
	0	Analog systems
Aeronautical Mobile	-6	Digital - 1 dB increase in the receiver noise level
	0	Analog systems
Maritime Mobile	-6	Digital - 1 dB increase in the receiver noise level
	0	Analog systems
Fixed	-9	Analog Frequency-Division-Multiplexed/Frequency-Modulated Systems
	-6	Digital - 1 dB increase in the receiver noise level
Radiolocation	-6	1 dB increase in the receiver noise of a search/track radar
Space Research (Space-to-Space)	-6	Criterion developed for near-Earth space research
No Specific Service (Experimental)	-6	Digital - 1 dB increase in the receiver noise level

3.1.2 Interference Thresholds for MMN Receivers

The MMN technical information, operational capabilities, and performance specifications, as provided by the AMF [1], were utilized to develop the I/N threshold.

Received Power Level

To calculate the interference criteria, it was necessary to calculate the predicted received power or carrier level (C) of the desired signal into the MMN receivers. Since the MCU is designed to be portable and carried by the patient, a separation of 1 meter between the MCU and the implanted ISD was assumed, and the received power level was calculated as shown in Equation 3-1.

$$C = EIRP_T - FSPL - BL + G_R - L \qquad (3\text{-}1)$$

where

C	=	received power level at the input of the receiver, dBm
$EIRP_T$	=	equivalent isotropic radiated power of the transmitter, dBm
FSPL	=	free space propagation loss between transmitter and receiver, dB
BL	=	body loss, dB
G_R	=	gain of receive antenna, dBi
L_S	=	system loss, dB

The FSPL was calculated as shown in Equation 3-2.

$$FSPL = 20 \log (4\pi d / \lambda) \qquad (3\text{-}2)$$

where

d	=	distance between the transmitter and receiver, m
λ	=	wavelength, m

Using 1 m for the distance and 0.67 m for the wavelength of an RF signal propagating at 450 MHz, a predicted FSPL of 25.46 dB between the MCU and ISD was calculated. Using the calculated FSPL and substituting the technical values provided by AMF, the predicted received power levels at the MCU and an implanted ISD are listed in Table 3-2.

Table 3-2. MMN Receive Power Levels

MMN Receiver	$EIRP_T$ (dBm)	FSPL (dB)	BL (dB)	G_R (dBi)	L_S (dB)	C (dBm)
MCU	-20	25.46	0	0	2	-47.46
ISD	0	25.46	20	-2.5	2	-49.96

Fade Margin

The Fade Margin (FM) is defined as the difference between the calculated received power level (C) and the received power level threshold (C_{TH}) that results in a 1 x 10^{-3} BER as shown in Equation 3-3.

$$FM = C - C_{TH} \tag{3-3}$$

where

C_{TH} = received power threshold resulting in a 1 x 10^{-3} BER, dBm

all other terms are previously defined.

Using the calculated received power levels and receiver thresholds provided by AMF, the predicted FM for both the MCU and ISD were calculated as shown in Table 3-3.

Table 3-3. MMN Fade Margin

MMN Receiver	C (dBm)	C_{TH} (dBm)	FM (dB)
MCU	-47.46	-88	40.54
ISD	-49.96	-90	40.04

Noise Level

The receiver noise level was calculated using Equation 3-4.

$$N = 10 \log(\eta) + 10 \log(k_B TBW) + 30 \tag{3-4}$$

where

N = receiver noise level, dBm

η = noise figure, dB

k_B = Boltzmann costant 1.379 x 10^{-23}, W/(^{o}K Hz)

T = reference temperature, 290 ^{o}K

BW = bandwidth, Hz

Substituting the technical parameters for the MCU and ISD receivers, the noise levels were calculated and the results are listed in Table 3-4.

Table 3-4. MMN Noise Level

MMN Receiver	η (dBm)	kT (dBm/Hz)	BW (MHz)	N (dBm)
MCU	11	-173.5	4.972	-96.1
ISD	8	-173.5	4.972	-99.1
BW- Bandwidth				

Carrier-to-Noise Power and Threshold Ratios

The Carrier-to-Noise power ratio (C/N) is defined as the difference between the calculated received power level (C) and the receiver noise level (N) as shown in Equation 3-6.

$$C/N = C - N \tag{3-6}$$

Using the calculated received power and noise levels, the C/N for both the MCU and ISD were calculated as shown in Table 3-5. Substituting the received power threshold for C, the Carrier-to-Noise threshold ratios $(C/N)_{TH}$ were calculated and are also shown in Table 3-5.

Table 3-5. MMN Carrier-to-Noise Ratios

MMN Receiver	C (dBm)	N (dBm)	C/N (dB)	C_{TH} (dBm)	$(C/N)_{TH}$ (dB)
MCU	-47.46	-96.1	48.64	-88	8
ISD	-49.96	-99.1	49.14	-90	9

Interference-to-Noise Threshold Ratios

Based on consultations with the AMF technical staff, acceptable performance of the MMN system is achieved with a FM of 20 dB. With a required FM of 20 dB and calculated C/Ns exceeding 48 dB, interference levels significantly stronger than the receiver noise level can be present and not adversely affect the performance of the MMN system.

To preclude potential RFI to the MMN receivers, the I/N must be equal to or less than the C/N level when faded below the FM and the $(C/N)_{TH}$ as shown in Equation 3-7.

$$I/N \leq C/N - FM - (C/N)_{TH} \tag{3-7}$$

Using Equation 3-7, the interference power thresholds for the MCU and ISD receivers are calculated by solving for I, and is listed along with the calculated I/N threshold in Table 3-6.

Table 3-6. MMN Interference-to-Noise Threshold Ratios

MMN Receiver	C/N (dB)	FM (dB)	$(C/N)_{TH}$ (dB)	I/N_{TH} (dB)	N (dBm)	I_{TH} (dBm)
MCU	48.64	20	8	20.6	-96.1	-75.5
ISD	49.14	20	9	20.1	-99.1	-79.0

3.2 RSD CALCULATIONS BETWEEN THE MMN AND GOVERNMENT C-E SYSTEMS

The RSD is the distance separation between the interferer and the receiver required to reduce the interference level below the interference threshold (I_{TH}). Substituting I_{TH} for I, the propagation loss required to reduce the interfering power level below the interference threshold of the receiver was calculated. The Required Propagation Loss (RPL) values were then entered into an inverse RF propagation model to calculate the RSD.

RPL

Substituting I_{TH} for I, the RPL from the transmitter to the receiver is calculated as shown in Equation 3-8.

$$RPL = EIRP_T - L_{DC} - L_S + G_R - FDR - I_{TH} \tag{3-8}$$

where

RPL	=	required propagation loss to reduce the interfering signal power from the transmitter below the interference threshold of the receiver, dB
L_{DC}	=	attenuation to account for the duty cycle of the transmitter, dB
G_R	=	gain of receive antenna in the direction of the interfering transmitter, dBi
FDR	=	frequency-dependent rejection of the interfering power in the receiver, dB
I_{TH}	=	interference threshold level of the receiver, dBm

all other terms are previously defined.

The transmit power was reduced to account for the amount of time that the equipment is actually transmitting as defined by the duty cycle as shown in Equation 3-9 and the results are listed in Table 3-7.

$$L_{DC} = 10 \log (\text{duty cycle}) \tag{3-9}$$

Table 3-7. MMN Duty Cycle Attenuation

MMN Transmitter	Duty Cycle (%)	L_{DC} (dB)
MCU	3	15
ISD	0.05	33

For Government C-E systems using directional antennas, the antenna gain at 10 degrees offset from the main beam was calculated using the Statistical Antenna Gain Model [6] and used in the calculations. This is a conservative value for all antenna coupling conditions beyond the 10 degree offset.

The FDR is the amount of power reduction at the output of the receiver IF filter due to bandwidth mismatch and off-tuning between the interfering transmitter and the receiver. As shown in Equation 3-10, the FDR can be decomposed into an on-tune component, referred to as On-Tune Rejection (OTR), and an off-tune component, referred to as Off-Frequency Rejection (OFR).

$$FDR = OTR + OFR \tag{3-10}$$

where

OTR = on-tune rejection of the receiver, dB

OFR = off-frequency rejection of the receiver, dB

Since the EMC analysis considered on-tune operation between the MMN and Government C-E Systems, only the OTR component is applicable in calculating the FDR. The OTR is the ratio, in dB, of the transmitter 3-dB bandwidth to the receiver 3-dB bandwidth as shown in Equation 3-11.

$$\begin{aligned} OTR &= 10 \text{ Log } (BW_T / BW_R), \text{ for } BW_T \geq BW_R \\ &= 0, \text{ for } BW_T < BW_R \end{aligned} \tag{3-11}$$

where

BW_T = bandwidth of the interfering transmitter, MHz

BW_R = bandwidth of the receiver, MHz

RSD

Once the RPL to preclude predicted interference between the transmitter and the receiver was calculated, then the value was entered into an inverse RF propagation model to calculate the RSD.

RF Propagation Models

The RF propagation models used to determine the RSD between the MMN and Government C-E systems were FSPL, Flat Earth [7], and Suburban Okumura/Hata/Davidson [8]. When calculating the RSD into terrestrial based Government C-E systems, the transition between the three models are as follows: FSPL was used from the transmitter to the break point distance, then the Flat Earth model was applied to 300 m away from the transmitter, then the Suburban Okumura/Hata/Davidson model was applied at distances beyond 300 m.

The break point distance is defined as the point where the radius of the first Fresnel intersects the ground between the transmitter and the receiver [7]. To calculate the RSD to airborne C-E systems, the FSPL and Suburban Okumura/Hata/Davidson models were used. The transition between these two models is defined by the horizon distance between the transmitter and the receiver. The FSPL model is used between the transmitter and the horizon distance and the Suburban Okumura/Hata/Davidson model is used beyond the horizon distance [7]. The FSPL is calculated using Equation 3-12.

$$FSPL = 32.4 + 20\log(f) + 20\log(d) \tag{3-12}$$

where

d = distance between the transmitter and receiver, km

all other terms are previously defined.

The break point distance is calculated as shown in Equation 3-13 [7].

$$d_b = \frac{4(h_{BS})(h)}{\lambda} \tag{3-13}$$

where

d_b = break point distance, m

h_{BS} = base station antenna height, m

h = MMN antenna height, m

all other terms are as defined previously.

The losses calculated using the Flat Earth model is shown in Equation 3-14.

$$L_{FEM} = 40\log(d) - 20\log(h_{BS}) - 20\log(h) \tag{3-14}$$

where

L_{FEM} = Flat Earth model propagation loss, dB

all other terms are previously defined.

The Suburban Okumura/Hata/Davidson model is defined as shown in Equation 3-15.

$$L_{sub} = L_{ur} - 2\left(\log\frac{f}{28}\right)^2 - 5.4 \tag{3-15}$$

where

L_{sub} = suburban propagation loss, dB

L_{ur} = urban propagation loss, dB

all other terms are previously defined and L_{ur} is calculated as shown in Equation 3-16.

$$L_{ur} = 69.55 + 26.15\log(f) - 13.82\log(h_{BS}) - a(h) + \\ + \left(44.9 - 6.55\log(h_{BS})\right)\left(\log(d)\right) - S_1(d) - S_2(h_{BS}, d) \quad (3\text{-}16)$$

where

$$S_1(d) = \begin{cases} 0 & d \le 64.38 \\ 0.174(d - 64.38) & d > 64.38 \end{cases} \quad (3\text{-}17)$$

$$S_2(h_{BS}, d) = 0.00784\left|\log(9.98/d)\right|(h_{BS} - 300) \quad h_{BS} > 300 \quad (3\text{-}18)$$

$$a(h) = \left(1.1\log(f) - 0.7\right)h - 1.56\log(f) + 0.8 \quad (3\text{-}19)$$

Using all three RF propagation models, a plot of the median value of the propagation path loss versus distance between the MMN at a height of 1.2 meters and Government C-E systems at antenna heights of 2, 32, and 5000 meters was calculated, and is shown in Figure 3-1.

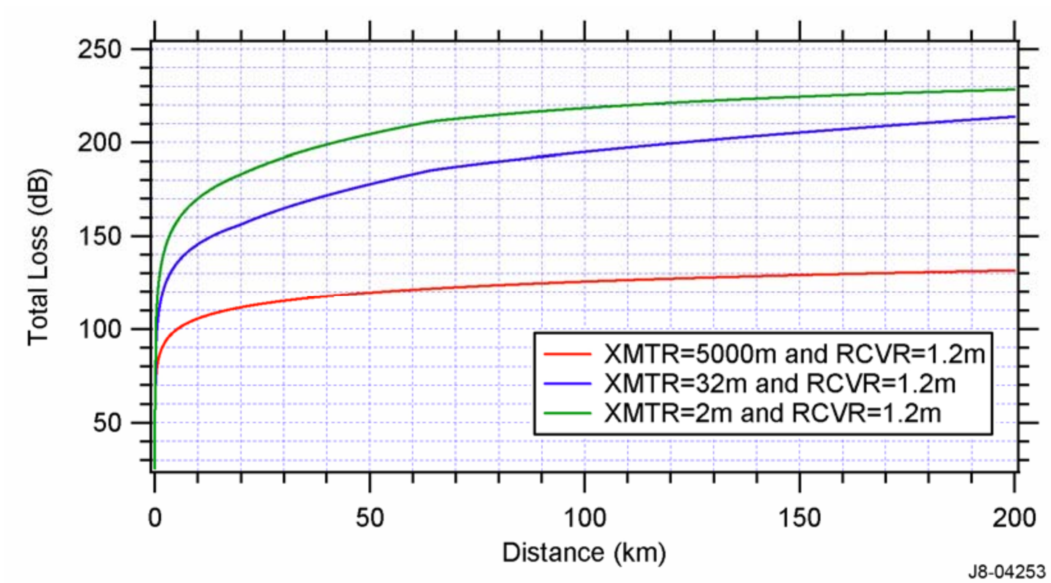

Figure 3-1. Propagation Path Losses vs. Distances

The plot in Figure 3-1 shows the predicted median propagation loss, which is the predicted propagation loss not to be exceeded 50% of the time. A propagation loss not to be exceeded 95% of the time was calculated by applying 8 dB of shadow loss [7, 8] to the median propagation loss as shown in Equation 3-20.

$$PL(95\%) = PL(50\%) + L_s \tag{3-20}$$

where

PL(95%) = propagation loss not to be exceeded 95% of the time, dB

PL(50%) = median propagation loss, dB

L_s = shadow loss, dB

The L_s varies based on a log-normal distribution density function with a standard deviation (σ) as shown in Equation 3-21.

$$p(L_s) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{L_s^{\,2}}{2\sigma^2}\right) \tag{3-21}$$

where

$p(L_s)$ = log-normal distribution density function of the propagation shadow loss

σ = Standard deviation, dB

The RSD was calculated using PL(50%) and PL(95%) and when the MMN is operating outdoors and indoors. The indoor RSD calculation includes the obstruction loss of a typical building in a suburban environment. The building obstruction loss of 12 dB is associated with a suburban morphology for signals propagating at 450 MHz. The building obstruction losses shown in Table 3-8 are based on the methodology described in [8].

Table 3-8. Building Obstruction Losses at 450 MHz

Morphology Type	Building Obstruction Loss (dB)
Dense Urban	20
Urban	18
Suburban	12
Rural	10

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4. RSD CALCULATION RESULTS

4.1 AMF MMN INTO GOVERNMENT C-E SYSTEMS

The RSDs calculated from both the MCU and ISD when operating outdoors and indoors into each Federal Government communication service type when both the PL(50%) and PL(95%) were applied are summarized in Table 4-1. The RSDs were calculated for all equipment nomenclatures assigned to each station class, and the largest, or worst-case, is listed. For C-E Systems utilizing directional antennas, the RSDs listed assume that the MMN is operating in the side lobe of the Government C-E system antenna.

410 – 420 MHz Frequency Band

When the MMN is operating outdoors in the 410 – 420 MHz frequency band and the PL(50%) is applied, the calculated RSDs into any terrestrial fixed or mobile non-radiolocation, Government C-E system are less than 0.52 km from the MCU, and 0.09 km from the ISD.

When the MMN is operating indoors in the 410 – 420 MHz frequency band and the PL(95%) is applied, the calculated RSDs into any terrestrial fixed or mobile non-radiolocation, Government C-E system are less than 0.30 km from the MCU, and 0.004 km from the ISD.

420 – 450 MHz Frequency Band

When the MMN is operating outdoors and using PL(50%), a worst case RSD of 5.98 km is calculated from the MCU into an airborne mobile radiolocation system. When the MCU is indoors and the PL(95%) is applied, the RSD decreases significantly to 0.6 km. In this scenario, since both the transmitter and Government C-E system are mobile, the probability of sustained interference into the airborne mobile receiver is expected to be extremely low.

Table 4-1. Largest Required Separation Distances from AMF into Environment

AMF as TX Government C-E System as RX		RSD (Outdoor)				RSD (Indoor)			
		MCU PL(50%) (km)	ISD PL(50%) (km)	MCU PL(95%) (km)	ISD PL(95%) (km)	MCU & Bldg PL(50%) (km)	ISD & Bldg PL(50%) (km)	MCU & Bldg PL(95%) (km)	ISD & Bldg PL(95%) (km)
Land Mobile	Base	0.31	0.04	0.30	0.02	0.30	0.01	0.30	0.004
	Mobile	0.30	0.04	0.23	0.02	0.18	0.01	0.12	0.004
Mobile	Base	0.34	0.04	0.30	0.02	0.30	0.01	0.30	0.004
	Mobile	0.30	0.04	0.25	0.02	0.20	0.01	0.12	0.004
Aeronautical Mobile	Base	0.34	0.03	0.30	0.01	0.30	0.01	0.26	0.003
	Air	1.34	0.02	0.53	0.01	0.34	0.004	0.13	0.002
Maritime Mobile	Base	0.30	0.02	0.30	0.01	0.25	0.004	0.12	0.002
	Mobile	0.30	0.01	0.26	0.004	0.10	0.003	0.06	0.001
Radiolocation	Ground Station	0.70	0.12	0.41	0.05	0.32	0.03	0.30	0.01
	Mobile Air	5.98	0.08	2.38	0.03	1.50	0.02	0.60	0.01
	Mobile Ground	0.29	0.02	0.18	0.01	0.15	0.01	0.09	0.002
No Specific Service (Experimental)	Base	0.37	0.06	0.30	0.03	0.30	0.02	0.30	0.01
	Mobile	0.31	0.07	0.30	0.05	0.30	0.03	0.21	0.01
Fixed		0.52	0.09	0.31	0.04	0.30	0.02	0.30	0.01
Space Research (Space-to-Space)		No Records	No Records	No Records	No Records	No Records	No Records	No Records	No Records
50% to 95% difference of 8 dB									
Bldg – Suburban Building Loss of 12 dB used in analysis RX – Receiver TX – Transmit									

4.2 GOVERNMENT C-E SYSTEMS INTO AMF MMN

The RSDs calculated from Government C-E systems into both the MCU and ISD operating outdoors and indoors when both PL(50%) and PL(95%) were applied are summarized in Table 4-2. The RSDs were calculated from all equipment nomenclatures assigned to each station class, and the largest, or worst-case, RSD for each station class is listed. For C-E Systems utilizing directional antennas, the RSD calculated assumes the MMN is operating in the side lobe of the Government C-E system antenna.

410 – 420 MHz Frequency Band

When the MMN is operating outdoors and applying PL(50%), the largest RSD from terrestrial fixed, non-experimental and non-aeronautical mobile Government C-E systems operating in the 410 – 420 MHz frequency band is 5.41 km into the MCU and 1.62 km into the ISD. The RSD values improve significantly when applying the PL(95%). In this case, the largest RSD from terrestrial fixed, non-experimental Government C-E systems is 3.26 km into the MCU and 0.98 km into the ISD. When the patient is indoors and 12 dB of obstruction loss is added to PL(95%), the calculated RSDs were less than 1.52 km into the MCU and 0.46 km into an implanted ISD.

When the MMN is operating outdoors and applying PL(50%), the largest RSD from an aeronautical mobile base station operating in the 410 – 420 MHz frequency band is 24.62 km into the MCU and 7.64 km into the ISD. When the patient is indoors and applying PL(95%), the RSDs were less than 7.15 km into the MCU and 2.06 km into an ISD.

The largest calculated RSD from C-E systems authorized to transmit in the Space Research service is 64.8 km. Transmitters with current frequency assignments in the Space Research services are authorized to transmit only from space; therefore, no RFI from these services into the MMN system is predicted.

420 – 450 MHz Frequency Band

The RSD calculated from high powered fixed radiolocation transmitters into the MMN system, when the patient is outdoors considering the average power of the transmitter and applying PL(50%), is 45.39 km into the MCU and 19.98 km into the ISD. The calculated RSDs improve significantly when applying PL(95%) and the patient is indoors with 12 dB of obstruction loss added to the propagation path loss. In this case, the RSD is 18.71 km into the MCU and 5.38 km into the ISD. It should be noted that the majority of the high powered radiolocation transmitters are located close to the US shoreline or borders and those antennas are directed away from the US.

The RSDs calculated from airborne mobile C-E transmitters, assuming a 5000 meter antenna height while applying the average transmit power and PL(95%), are 170.42 km into the MCU and 19.14 km into the ISD when the patient is indoors. Even though this scenario results in large RSDs between Government C-E systems and the MMN receivers, the airborne mobility of the transmitters is expected to significantly reduce the probability of occurrence.

Table 4-2. Largest Required Separation Distances from Environment into AMF

AMF as RX Government C-E System as TX			RSD (Outdoor)				RSD (Indoor)			
			MCU PL(50%) (km)	ISD PL(50%) (km)	MCU PL(95%) (km)	ISD PL(95%) (km)	MCU & Bldg PL(50%) (km)	ISD & Bldg PL(50%) (km)	MCU & Bldg PL(95%) (km)	ISD & Bldg PL(95%) (km)
Land Mobile	Base		4.05	1.22	2.44	0.73	1.90	0.57	1.14	0.34
	Mobile		0.86	0.31	0.56	0.30	0.46	0.30	0.30	0.21
Mobile	Base		2.90	0.87	1.76	0.53	1.36	0.41	0.82	0.30
	Mobile		1.40	0.51	0.91	0.33	0.74	0.30	0.48	0.30
Aeronautical Mobile	Base		24.62	7.64	15.74	4.52	12.10	3.48	7.15	2.06
	Air		157.38	17.66	62.66	7.04	39.54	4.44	15.74	1.78
Maritime Mobile	Base		1.25	0.40	0.78	0.30	0.61	0.30	0.38	0.30
	Mobile		1.20	0.43	0.78	0.30	0.63	0.30	0.41	0.30
Radiolocation	Ground Station	PEAK	70.39	34.52	52.52	24.26	45.48	20.04	33.10	11.86
		AVG	45.39	19.98	33.06	11.82	27.78	9.10	18.71	5.38
	Mobile Air	PEAK	296.08	296.07	296.08	294.10	296.08	185.56	296.07	73.88
		AVG	296.07	191.20	296.08	76.14	296.08	48.04	170.42	19.14
	Mobile Ground	PEAK	11.99	3.78	7.82	6.36	6.30	2.00	4.10	1.30
		AVG	11.99	3.78	7.82	6.36	6.30	2.00	4.10	1.30
No Specific Service (Experimental)	Base		24.37	8.08	15.84	4.96	12.40	3.88	7.60	2.38
	Mobile		3.47	1.25	2.26	0.82	1.82	0.66	1.19	0.43
Fixed			5.41	1.62	3.26	0.98	2.54	0.76	1.52	0.46
Space Research (Space-to-Space)			64.80	7.30	Not Applicable	Not Applicable	16.30	1.80	Not Applicable	Not Applicable
50% to 95%, difference of 8 dB										
Bldg – Suburban Building Loss of 12 dB used in analysis										

5. MMN INTERFERENCE MITIGATION TECHNIQUES

The MMN is proposing to operate on a non-interference/non-protected basis in the 413 – 457 MHz frequency band; therefore, AMF designed the system with multiple techniques to mitigate interference into and from on-tune services as described in the design specification [1]. These techniques include: Dynamic Channel Switching between four channels with 3 designated in the 413 – 450 MHz frequency band and the 4th channel in the 450 – 457 MHz frequency band allocated for commercial services, notching or frequency domain excision of narrow bandwidth interfering signals, the effect of the communication timing of the MNN system and the duty cycle of the radiolocation transmitter, communications coding and forward error correction techniques. These interference mitigation techniques as applied to the results of the RSD calculations are described below.

5.1 DYNAMIC CHANNEL SWITCHING

AMF designed the system to be frequency agile and proposes to operate on one of four, 6 MHz bandwidth channels. The MCU monitors the noise level of each channel and operates on a channel where the noise level will not result in interference into the MCU receiver. If an external RF signal is present and increases the channel noise to an unacceptable level, the MCU dynamically switches to an RF channel with a noise level that will not result in interference. The RSDs calculated between the MMN and Government C-E systems assumed on-tune operation and did not consider the Dynamic Channel Switching of the MMN to avoid potential electromagnetic interference.

The emission bandwidths of the majority of the Government C-E systems considered in this analysis occupy significantly less bandwidth than the MMN. Therefore, based on the dynamic channel switching of the MMN and the narrow bandwidth of Government C-E systems, the MMN system could detect a Government C-E system operating nearby and switch to an adjacent channel. When the MMN system is operating on adjacent channels with approximately 8 MHz of frequency separation, the channel filters of the MCU will provide 45 dB of attenuation as described in the MMN Design Specification [1].

5.2 NOTCHING (FREQUENCY DOMAIN EXCISION)

Compared to the narrow bandwidth land mobile radio systems assigned to operate in the 410 – 420 MHz frequency band, the MMN employs a wideband TDMA architecture with a low power spectral density. The MMN digitizes the RF signals and the narrow bandwidth interfering signals are identified with a peak power search algorithm. Once identified, the MMN excises the narrow bandwidth signals with negligible degradation to the MMN S/N. The wideband, low power spectral density TDMA architecture and digital signal processing techniques were designed specifically to mitigate potential RFI from narrow bandwidth land mobile radios.

5.3 MMN SYSTEM ARCHITECTURE (TIMING/DUTY CYCLE)

The RF link of the MMN system does not continuously transmit, whereby the MCU operates with a duty cycle of 3% and the ISD operates with a 0.05% duty cycle. If an interfering transmitter with a similarly low duty cycle, such as a radar, is in the environment, the low probability of simultaneous transmissions may allow the MMN system to operate without interference even when it is located nearby and within the calculated RSD. Further determination of the probability of simultaneous transmissions could be examined through statistical analyses.

5.4 CODING AND FORWARD ERROR CORRECTION TECHNIQUES

The MMN system employs multiple coding schemes including: Reed-Muller, Golay, Flag, and the 5/32 Code to protect the system from RFI as described in the design specification [1].

> These codes are the basic mechanism used to protect the system from passing erroneous messages over the communication link. Errors from any source can be detected and in many cases corrected. Messages with detected errors can be retransmitted using the retransmission protocol. The error detection and correction processors are also used to evaluate the channel quality and make basic decisions concerning the need to change channels or for the application to enter a safe or reduced operational mode.

5.5 ADDITIONAL CONSIDERATIONS

Protected Fade Margin

The RSDs listed in Section 4 are the largest, or worst-case, values calculated by service type and station class assuming on-tune operation while protecting the 20 dB FM of the AMF MMN system. Based on the operational frequency range and since the typical distance between MCU and ISD is expected to be less than 2 m, it is likely that the MMN system will meet performance requirements with a smaller designed fade margin. If the interference calculations were protecting a smaller fade margin, the calculated RSDs would be significantly reduced.

Environmental Factors

A significant number of the current Government C-E system frequency assignments are for mobile transmitters, fixed stations on military bases and radiolocation systems transmitting away from coastlines and borders. Based on these factors, the current deployment of Government C-E systems coupled with the small percentage of the population expected to utilize the MMN system decreases the probability that the MMN system would operate within the RSDs listed in Section 4.

ISD Error Response and Default Activity

The TDMA architecture and the employed coding techniques and frame structure of the data is designed so that the implanted ISDs only produce electric stimulations when specifically requested by the MCU. If the ISD is unable to decode an MCU command, it transmits a negative acknowledgement code and the MCU retransmits the command. If an ISD cannot successfully decode seven consecutive transmissions, it assumes communication is lost and enters a safe mode until the communications link is restored [1]. This default activity prevents the implanted ISD from reacting to interfering signals that cannot be successfully decoded and the ISD does not resume operation until it successfully resynchronizes communication with the MCU.

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6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The objective was to analyze the EMC of the proposed MMN with Federal Government C-E systems authorized to operate in the 410 – 450 MHz frequency band. The conclusions of the EMC analysis and recommendations are described below.

6.1.1 MMN Transmitters into Government C-E systems

When the MMN is operating outdoors and applying PL(95%), the largest calculated RSD from the MMN transmitters into any fixed or mobile, non-airborne Government C-E system is less than 0.41 km from an MCU and less than 0.05 km from an ISD. When the MMN is operating indoors and 12 dB of building obstruction loss is added to the propagation loss, the calculated RSD to any fixed or mobile, non-airborne Government C-E system is less than 0.30 km from the MCU and .01 km from the ISD. When the MMN is operating outdoors and applying PL(95%), the largest calculated RSD from the MMN transmitters into an airborne mobile radiolocation system is 2.38 km. When the MMN is operating indoors and applying PL(95%), the largest calculated RSD into an airborne mobile radiolocation is 0.6 km.

These relatively small RSDs result from the low EIRP and duty cycle of the MMN transmitters combined with the low antenna heights of the MMN. These factors coupled with the frequency agility of the MMN portable transmitters, anticipated low volume of MMN systems with random geographic distribution and the current distribution of the Government C-E systems indicates that the MMN system should be operationally compatible and not cause unacceptable interference into Government C-E systems currently authorized to operate in the 410 – 450 MHz band.

6.1.2 Government C-E systems into MMN Receivers

When the MMN is operating outdoors and applying PL(95%), the potential for RFI from fixed Government land mobile base stations is predicted to occur at distances less than 2.44 km with the MCU and 0.73 km with the ISD. When the MMN is operating indoors, the calculated RSDs from land mobile base stations are reduced to 1.14 km with the MCU and 0.34 km with the ISD. When the patient is indoors and applying PL(95%), the calculated RSDs from aeronautical mobile base stations operating in the 410 – 420 MHz frequency band are less than 7.15 km into the MCU and 2.06 km into an ISD.

The interference mitigation techniques of notching and dynamic channel switching described in Section 5 may effectively eliminate the potential for RFI and allow the MMN to simultaneously operate with Government C-E systems at distances less than the calculated RSD.

When the MMN is operating outdoors and applying PL(95%), the potential for RFI from Government high powered fixed radiolocation transmitters is predicted to occur at separation distances of less than 33.06 km into the MCU and less than 11.82 km into an ISD. When the MMN is operating indoors, the calculated RSDs are reduced to 18.71 km with the MCU and 5.38 km with the ISD. However, the MMN system may operate without interference at distances less than the predicted RSDs. This is due to the duty cycles of the MMN and the interfering radiolocation transmitter creating a low probability that the desired and interfering signals will be received simultaneously resulting in a data collision.

The RSDs calculated from airborne mobile radiolocation transmitters, assuming a 5000 meter antenna height while applying the average transmit power and PL(95%), are 170.42 km into the MCU and 19.14 km into the ISD when the patient is indoors. Even though this scenario results in large RSDs between airborne radiolocation transmitters and the MMN, the airborne mobility of the transmitters is expected to significantly reduce the probability of occurrence. This low probability of occurrence combined with the low probability that the MMN and airborne radiolocation signals will be received simultaneously coupled with the dynamic channel switching capability of the MMN may effectively eliminate the potential for RFI from airborne mobile radiolocation transmitters.

AMF designed the MMN with specific techniques to mitigate interference from incumbent Government C-E systems as described in Section 5 and summarized in the following Section 6.1.3.

6.1.3 MMN Interference Mitigation Techniques

AMF designed the MMN to operate interference free in the presence of incumbent communication services operating in the 413 – 457 MHz frequency band. The employment of four, 6 MHz bandwidth channels spanning three separate frequency allocations coupled with the ability to dynamically switch between channels should enable the MMN to be operationally compatible with incumbent Federal Government operations.

When the MMN is operating on channel 1, the current geographic distribution and locations of Federal Government land mobile C-E systems and relative low volume of anticipated MMN systems create a very low probability that the MMN system will be operating within the calculated RSD of less than 300 m as listed in Tables 4-1 and 4-2. If the patient is within the RSD, and the MMN is operating on channel 1 while interfering signals from on-tune narrowband land mobile Federal Government systems are present, and the noise level in the remaining three channels prevent the MMN from switching channels, the frequency domain excision technique to remove narrow band interfering signals should enable the MMN system to operate without interference.

If the MMN operates on channels 2 and 3, it shares the spectrum with Federal Government high power radiolocation systems operating near the US coast line and transmitting outside the US borders. Therefore, a low probability that the MMN system will be operating within the calculated RSDs is expected. If the MMN is operating on channels 2 or 3 and interfering signals from radiolocation transmitters are received, the duty cycles of the two systems should result in a very low probability that simultaneous transmissions resulting in interference are received. In the event that simultaneous on-tune transmissions between these types of systems occur, the coding schemes and forward error correction techniques of the MMN should allow it to successfully operate.

If interfering signals from Government C-E systems in channels 1 through 3 are simultaneously present, the MMN would operate on channel 4, which is shared with commercial services. The MMN interference mitigation techniques should enable the MMN to operate without causing or receiving interference from Federal Government C-E systems operating in the 410 – 450 MHz frequency range.

6.2 RECOMMENDATIONS

The AMF interference mitigation techniques as described in the design specification [1] and summarized above may effectively eliminate the potential RFI and allow the AMF to operate simultaneously with Government C-E systems at distances far less than the calculated RSD. Testing the AMF interference mitigation techniques to ensure their effectiveness is recommended. In addition, testing is recommended to validate the body loss used in the EMC analysis and EIRP of the ISD when measured just outside the body.

If the FCC accommodates Wireless Medical Device operations in the 413 – 450 MHz frequency band, it is recommended that it be accommodated on a non-interference basis. Further, the FCC should require future wireless medical systems to perform an EMC analysis with Government systems, require systems to employ interference mitigation techniques similar to those included in the AMF MMN Design Specification [1] and perform testing to ensure the mitigation techniques perform as described.

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7. REFERENCES

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8. ACRONYM LIST

AMF	Alfred Mann Foundation
BER	Bit Error Rate
BL	Body Loss
C	Carrier Level
C-E	Communications-Electronics
C/N	Carrier-to-Noise power ratio
EIRP	Equivalent Isotropic Radiated Power
EMC	Electromagnetic Compatibility
FCC	Federal Communications Commission
FDR	Frequency Dependent Rejection
FM	Fade Margin
FRRS	Frequency Resource Record System
FSPL	Free Space Path Loss
GMF	Government Master File
IF	Intermediate Frequency
I/N	Interference-to-Noise ratio
ISD	Interacting System Device
MCU	Master Control Unit
MMN	Medical Micropower Network
OFR	Off-Frequency Rejection
OTR	On-Tune Rejection
PL	Propagation Loss
QPSK	Quadrature Phase-Shift Keying
RF	Radio Frequency
RFI	Radio Frequency Interference
RPL	Required Propagation Loss
RSD	Required Separation Distance
RX	Receiver
TDMA	Time Division Multiple Access
TX	Transmit
UHF	Ultra High Frequency
US	United States

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